COUNTING STELLER SEA LION PUPS IN ALASKA: AN EVALUATION OF MEDIUM-FORMAT, COLOR AERIAL PHOTOGRAPHY

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ABSTRACT

Estimates of Steller sea lion (*Eumetopias jubatus*) pup production are valuable for estimating population trend and size. Currently in Alaska, pups are counted by visiting rookeries, driving older animals into the water, then walking through the rookeries and counting the pups, a highly disruptive procedure. At smaller rookeries, with good vantage points, pups are occasionally counted from the periphery of rookeries without disturbing the sea lions. We evaluated counts made from medium-format, color, aerial photographs as an alternative to drive counts and peripheral counts. Neither the peripheral counts nor the aerial photographic counts disturbed animals on the rookeries. There were strong 1:1 linear relationships between photographic counts and drive counts ($r^2 = 0.966$, $P < 0.001$) and between photographic counts and peripheral counts ($r^2 = 0.999$, $P < 0.001$). Precision was similar for all three methods of counting. We suggest that medium-format, color, aerial photography is appropriate for routine surveys of Steller sea lion pups in Alaska because it is not disruptive to the hauled-out sea lions and provides comparable estimates with similar precision to drive and peripheral counts. Large areas can be rapidly surveyed during periods of good weather with a minimum of manpower.

Key words: Steller sea lion, *Eumetopias jubatus*, census, pup counts, aerial photography.

In May 1997, Steller sea lions (*Eumetopias jubatus*) in the Gulf of Alaska, Bering Sea, and Aleutian Islands were classified as endangered under the U.S.

Endangered Species Act. This action was in response to a population decline over the past 30 years, estimated at over 80% (Braham *et al.* 1980, Merrick *et al.* 1987, Loughlin *et al.* 1992, NMFS 1995, Trites and Larkin 1996). This "western stock" of Steller sea lions is recognized as being genetically distinct from an "eastern stock" that includes sea lions from Southeast Alaska to California (Bickham *et al.* 1996). Steller sea lion numbers have increased or remained stable throughout the range of the eastern stock except in Southern California (NMFS 1995, Calkins *et al.* 1999).

Key components of a conservation program for Steller sea lions are estimates of abundance and population trend. Currently two approaches are used, counts of non-pups (adults and juveniles) on rookeries and haul-outs and counts of pups on rookeries (Calkins *et al.* 1999). Counts of non-pup Steller sea lions are typically obtained from 35-mm aerial photographs taken during the breeding season (Merrick *et al.* 1987). This method provides an index of population size but not an estimate of the total population, since the proportion of the population present on rookeries and haul-outs when surveys are conducted is variable and unknown (NMFS 1992).

Counts of pups are generally considered a better way to follow population trends for many species of pinnipeds (Berkson and DeMaster 1985). Steller sea lion pups remain on the rookery for about a month following birth, allowing for a nearly complete count (Trites and Larkin 1996, Calkins *et al.* 1999). Counts of pups on rookeries can be converted to an approximate estimate of total population size based on an estimated ratio of pups to non-pups in the population (Calkins and Pitcher 1982, Trites and Larkin 1996) although variations in birth and survival rates and population structure will affect this ratio.

In Alaska, pup numbers have generally been estimated with a technique known as drive counts. Personnel are landed on a rookery from a boat or helicopter, non-pups are herded into the water, and the pups, which usually remain on land, are counted. These counts are conducted after most pups are born but before they become proficient swimmers. Although counts conducted in this manner are considered relatively accurate, they are highly disruptive and may increase pup mortality due to drowning, trampling, and female abandonment (Lewis 1987). Pups can sometimes be counted from vantage points along the periphery of rookeries, but not all rookeries contain suitable observation sites. There is a need for another technique that is not disruptive, is relatively accurate and precise, and can be applied to a wide range of sites.

Faced with a similar challenge, scientists from the National Marine Fisheries Service, Southwest Fisheries Science Center, have been using large and medium-format, color aerial photography to count pinnipeds as an alternative to ground counts. They found counts of northern elephant seal (*Mirounga angustirostris*) pups and adults and California sea lion (*Zalophus californianus*) pups made using high-resolution photographs were as accurate and precise as those made from the ground (Lowry and Perryman 1992, Lowry *et al.* 1996, Lowry 1999). Counts of Steller sea lion pups from medium-format, aerial photographs at Año Nuevo, California, were higher and more precise than those made from

a distant vantage point on the ground (Westlake *et al.* 1997). However, no comparisons were made between the aerial counts and drive counts, nor were evaluations made of the utility of medium-format photography on different types of rookery topography.

Based on these results, we designed a study to evaluate medium-format aerial photography as an alternative to peripheral counts and drive counts of Steller sea lion pups on rookeries in Alaska. Specific hypotheses evaluated were:

1. The number of pups counted on medium-format aerial photographs are similar to those obtained during drive counts.
2. The number of pups counted on medium-format aerial photographs are similar to those obtained from peripheral ground counts.
3. The precision of pup counts from photographs, peripheral counts, and drive counts are similar.
4. Aerial photographic surveys do not disturb Steller sea lions on rookeries.

MATERIALS AND METHODS

Pups were counted by using medium-format aerial photography on 10 rookeries in the Gulf of Alaska and Southeast Alaska (Table 1, 2) during late June and early July of 1997 and 1998, the optimal dates for peak pup counts (Sandegren 1970, Pitcher and Calkins 1981, Withrow 1982, Lewis 1987). These rookeries included a variety of topographies and substrates common to Steller sea lion rookeries in Alaska. Drive counts and/or peripheral counts were conducted for comparison at each of these rookeries during at least one year. Replicate counts for each technique (with single or multiple observers) were performed whenever possible. Drive counts were replicated by using multiple observers during a single count. Peripheral count data, used for comparison to aerial photographic counts, were taken from the counts closest in time to the aerial survey. Pup numbers on rookeries in Alaska are relatively stable for about a two-week period beginning late in the pupping period (unpublished data). Comparative counts were conducted within a week of each other in all but one instance (Table 1). The Marmot Island peripheral count was conducted more than two weeks later than the aerial photography in 1997. Average birth dates appear to be relatively stable at individual rookeries in Alaska (unpublished data). Due to difficult terrain and obstinate adult sea lions, a portion of the Hazy Island drive count in 1997 and the entire Outer Island drive count in 1998 were performed from a hovering helicopter.

Aerial photographic pup counts—Aerial photographs were taken with a medium-format (126-mm) KA-76 Chicago aerial military reconnaissance camera (Lowry *et al.* 1996). The camera had forward image motion compensation which moves the film in the opposite direction and at the same speed as the plane moves forward, providing a photograph with a minimum of blur. Photographs were taken with 80% overlap, therefore each point surveyed was on at least four adjacent, overlapping frames. Kodak Aerochrome HS Film SO-359 was used, and developed as a series of 115 × 115 mm color transparency

Table 1. Number of replicates (*n*), means, ranges, and coefficients of variation (CV) for drive counts and aerial photographic counts of Steller sea lion pups by location and year.

Location	Year	Drive counts					Photo counts				
		n	x̄	Range	CV	Survey date	*n*	x̄	Range	CV	Survey date
White Sisters	1997	3	205	195–215	5.31	July 5	6	225	203–251	8.29	July 1,2
White Sisters	1998	1	282	—	—	July 4	3	267	262–272	2.04	July 1
Hazy Island	1997	1	1,157	—	—	July 7	3	906	889–925	2.16	July 1
Hazy Island	1998	2	1,199	1,154–1,243	5.91	July 4	3	1,287	1,204–1,329	6.03	July 1
Lowrie Island[a]	1997	2	691	667–714	0.93	June 29	5	837	686–1,024	16.22	July 1
Lowrie Island	1998	2	1,061	1,012–1,110	7.35	July 5	2	1,078	1,044–1,111	4.95	July 1
East Rock	1997	2	139	131–147	9.16	June 29	4	97	89–111	10.65	July 1
East Rock	1998	2	58	56–60	4.78	July 5	2	65	61–68	8.63	July 1
North Rock	1997	2	1,275	1,166–1,383	13.55	June 29	4	1,119	1,075–1,147	3.28	July 1
North Rock	1998	2	996	946–1,046	8.03	July 4	2	1,122	1,114–1,130	1.13	July 1
C Horn/SL Rock	1997	2	696	691–701	1.15	June 29	3	686	667–701	2.72	July 1
C Horn/SL Rock	1998	2	644	621–667	5.10	July 4	2	754	751–756	0.52	July 1
Marmot Island	1998	3	642	576–700	11.35	July 1	2	634	633–644	0.01	July 2
Sugarloaf Island[b]	1998	3	703	681–725	5.58	July 4	3	672	650–684	3.12	July 2
Outer Island	1998	2	113	112–113	0.71	July 5	3	106	100–112	4.34	July 2
Seal Rocks	1998	3	542	532–555	2.39	June 29	3	555	547–555	2.54	July 2

[a] The photographs for Lowrie Island in 1997 were the poorest quality obtained due to blur and underexposure. This is reflected in the high CV.

[b] Pup mean determined by combining drive counts and peripheral counts for different sections of the rookery; CV for each count method determined by using the rookery sections counted by each method.

Table 2. Number of replicates (n), means, ranges, and coefficients of variation (CV) for peripheral counts and aerial photographic counts of Steller sea lion pups by location and year.

Location	Year	Peripheral counts					Photo counts				
		n	$\bar{x}$	Range	CV	Survey date	n	$\bar{x}$	Range	CV	Survey date
Marmot[a]	1997	1	762	—	—	July 15, 23	3	746	739–759	1.60	July 2
Marmot	1998	6	630	615–645	3.56	July 1	2	634	633–634	0.01	July 2
Sugarloaf	1997	1	673	—	—	July 3	3	654	644–662	1.82	July 2
Sugarloaf[a]	1998	3	703	681–725	4.50	July 4	3	672	650–684	3.10	July 2
Fish	1997	4	120	101–134	12.73	July 2	4	123	117–131	5.46	July 2
Fish	1998	6	147	127–161	8.11	July 2	3	151	134–170	12.91	July 2

[a] Pup mean determined by combining drive counts and peripheral counts for different sections of the rookery; CV for each count method determined by using the rookery sections counted by each method.

frames. The camera was mounted vertically in the floor of an Aerocommander 680FL fixed-wing aircraft. When a section of rookery was seen to contain a high density of pups, that area was often photographed a second time to ensure a quality series of photographs would be obtained. In 1997, photographs were taken from an altitude of 210 m or 240 m. In 1998, photographs were taken from 195 m or 210 m and slightly overexposed to improve contrast between pups and the substrate. Photographs from all altitudes and exposures produced acceptable images for counting, although photographs of the Lowrie Island rookery in 1997 were slightly blurred and underexposed due to marginal weather conditions.

The color transparencies were viewed through a variable power stereo-microscope on a light table. The microscope was mounted so it could be moved over the light table to overlapping frames making it possible to get a different view of questionable animals. Clear acetate sheets were placed over the frames, and pups were marked while being counted with a hand counter. Pups that were obviously dead (in amniotic sac, partially scavenged, and in tidal debris) were counted separately during both the photographic counts and the ground counts. There may have been a slight bias towards counting dead pups as live pups in the photographic counts, however dead pups always comprised a small proportion of the total (<1%). The acetate sheet was then moved to overlapping frames to double check for errors. Some of the rookeries were counted more than once per person. When a repeat count was performed, the hand counter was masked and there was at least a four-day period between counts to avoid bias resulting from the prior count and assure independence of the replicates (Lowry 1999).

Data analysis—The mean and coefficient of variation were determined for pup count data from each rookery, count technique, and year. We used least-squares linear regression to evaluate the relationship between the aerial photographic counts and both drive counts and peripheral counts. The means of replicate counts were used in the regressions because the mean is normally used for reporting pup numbers (this results in slightly higher r^2 values and smaller SEs than would be obtained with individual observations). We used square root transformations of the mean counts in the regressions because the variance of the counts increased with the size of the counts (Sokal and Rohlf 1995). Photographic counts were the independent variables in the regressions as aerial photography was being tested for how well it predicted the value of drive and peripheral counts. The regression slopes were tested for a significant difference from one, and the intercepts tested for a significant difference from zero (Steel and Torrie 1980). A slope equal to one and an intercept equal to zero indicate the two methods produce the same count.

The coefficient of variation was used to compare relative precision between counts of pups obtained from aerial photographic, peripheral, and drive counts (Lewontin 1966). Precision comparisons were made for rookeries and years where variances could be computed (Table 1, 2). Coefficients of variation were calculated with correction for small sample sizes (Sokal and Braumann 1980). Coefficients of variation for drive and peripheral counts were compared to
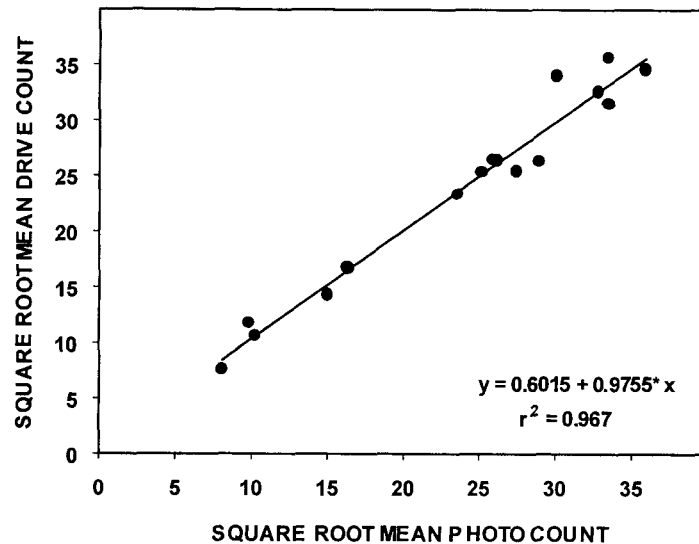
Figure 1. Comparison of aerial photographic and drive counts of Steller sea lion pups at 10 rookeries in Alaska during 1997 and 1998.

coefficients of variation from photographic counts using a t-test (Sokal and Rohlf 1995).

RESULTS

The number of replicates, mean counts, and coefficients of variation for photographic and drive pup counts are presented in Table 1. There was a strong linear relationship between photographic counts and drive counts of pups (Fig. 1). This regression accounted for a significant amount ($P < 0.001$, $r^2 = 0.967$) of the variation in the data. The regression slope ($b = 0.976$, SE $= 0.0485$) was not different from one ($P = 0.623$), nor was the intercept (a $= 0.602$, SE $= 1.237$) different than zero ($P = 0.634$). There was no significant difference ($P = 0.31$) between the coefficients of variation for photographic and drive counts.

The number of replicates, mean counts, and coefficients of variation for photographic and peripheral pup counts are listed in Table 2. There was a strong linear relationship between photographic counts and peripheral counts (Fig. 2) with the regression accounting for a significant amount ($P < 0.001$, $r^2 = 0.999$) of the variation in the data. The regression slope ($b = 1.031$, SE $= 0.014$) was not different from one ($P = 0.091$), nor was the intercept (a $= -0.522$, SE $= 0.316$) different than zero ($P = 0.174$). There was no significant difference ($P = 0.38$) between the coefficients of variation for photographic and peripheral counts.

During aerial surveys many sea lions were seen looking up at the plane, but none were observed "spooking" or "stampeding" to the water. Observers
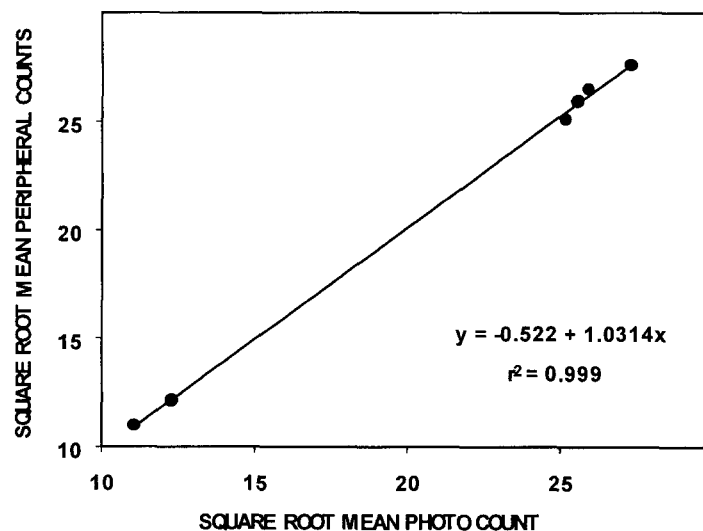
Figure 2. Comparison of aerial photographic and peripheral counts of Steller sea lion pups at Marmot, Sugarloaf, and Fish Islands in 1997 and 1998.

watching the rookery during the aerial surveys at Fish and Marmot Islands in 1998 did not see disturbance responses.

DISCUSSION

We were unable to reject hypotheses 1, 2, and 3 as there were no significant differences between estimates from photographic counts and either drive counts or peripheral counts, precision was similar, and there were strong 1:1 linear relationships that explained most of the variation in the data. Furthermore, our observations of no strong reactions by the sea lions to the survey aircraft led us to conclude the aerial surveys were not disruptive to the rookeries (hypothesis 4), particularly in contrast to drive counts where nearly all older animals and some pups are forced into the water.

No bias was observed for any counting technique, although there was greater variation between photographic and drive counts as the numbers of pups increased (Fig. 1). For areas with high pup densities, aerial photographs may provide more accurate estimates of pup abundance than drive counts because of the movement and intermingling that occurs when large groups of sea lions are disturbed. Variation is inherent in all three counting techniques, as demonstrated by the coefficients of variation for the counts (Table 1, 2). Factors such as rookery topography, weather, animal behavior, animal density, piloting skills, photographer skills, and observer performance affect accuracy and precision. Aerial photographs provide an advantage as they can be slowly and methodically counted and recounted, unlike peripheral and drive counts which must be completed quickly because of animal movement. The integrity of photographic coverage can be compromised by bad weather, equipment failure,

or operator error. An example is the 1997 count at Lowrie Island where the photographs were blurred and underexposed due to poor weather conditions, resulting in high variability in the replicate counts (Table 1). Unfavorable weather conditions also limit the effectiveness of other surveys techniques, including aerial surveys of non-pups and drive and peripheral counts of pups.

The decision about which technique (aerial photographs, peripheral counts, or drive counts) to use for counting Steller sea lion pups should not be based on concerns about relative accuracy and precision alone, as they did not differ between techniques. Other factors such as disturbance concerns, cost, ancillary data to be collected, and availability of equipment and manpower should be considered. Unlike drive counts, photographic and peripheral counts do not disturb the rookery. Aerial photographic surveys can be conducted over a broad area during windows of good weather much faster than peripheral or drive counts. Both pups and non-pups can be counted from aerial photographs, potentially eliminating separate surveys of non-pups. Aerial photographs provide permanent records of animal abundance, distribution, and rookery use and may be useful for retrospective studies. Peripheral counts can be used at rookeries with good vantage points, and data on population composition, behavior, marked animals, and life histories can also be collected. If activities such as branding or scat collections are to be conducted on rookeries then drive counts may also be conducted with little additional disturbance.

In conclusion, we suggest that medium-format aerial photographic counts are appropriate for routine estimation of Steller sea lion pup abundance in Alaska, at least in the portion of the range covered by this study. This technique does not disturb sea lions on rookeries and provides comparable estimates of pup production with a similar degree of precision as drive counts and peripheral counts. Large areas can be rapidly surveyed with a minimum of manpower.

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